Upper Ocean Mixing & Coastal Mixing AASERT

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LONG-TERM GOALS

My long-term goals are to identify and quantify the major mixing processes in the upper ocean and to relate them to the larger-scale processes producing the mixing as quantitatively as possible. When successful, this will take the form of parameterizations that can be used in numerical models.

OBJECTIVES

My scientific objectives are to measure mixing directly with microstructure sensors and to relate these measurements to the larger scales producing the mixing in such a way that the results can be compared with either the large-scale changes resulting from the mixing or with theoretical predictions of mixing rates. My technological objectives are to develop instruments and sensors to measure mixing parameters.

APPROACH

Because a first-order understanding of mixing in the upper ocean is rapidly being developed, our approach has shifted to obtaining a similar understanding of mixing near coasts and in estuaries. Because dissipation rates are higher in these waters, we have also shifted our technological developments to improve the spatial resolution of microstructure sensors and to adapt open-ocean measurements of finescale velocity to shallow water.

WORK COMPLETED

Emin Ozsoy and I finished our analysis of flow and mixing in the Bosphorus using the densely-spaced profiles we collected throughout the strait in 1994. We submitted the paper to JGR and have presented the data at several scientific meetings.

Jody Klymak is within a few weeks of finishing his Ph.D. dissertation using data we collected during the 1995 Knight Inlet Experiment. One paper is being reviewed, another will be submitted when he returns from a cruise he is joining as part of a postdoc with Jim Moum at Oregon State University. He has a good draft of the third, and last, paper based on these data. After the cruise, Jody will return to defend his dissertation in early January.

Jen MacKinnon finished analyzing the links between between shear and mixing on the New England Shelf in late summer 1996. We took the data during the first phase of the Coastal Mixing and Optics (CMO) program. She is finishing the draft, but it may not be submitted until November, when Gregg will return from a long cruise. This paper will be the first part of her Ph.D. dissertation.

Miller and Gregg modified the third Modular Microstructure Profiler (MMP3) to carry a N. Brown acoustic current meter and have deployed it in several oceanic and estuarine environments. Under a separate contract, Matthew Alford is analyzing the data to remove the effects of vehicle motion.

RESULTS

One aspect of our measurements in Knight Inlet was collecting systematic microstructure measurements in different regimes of the fjord. Our sampling strategy focused near a very sharp sill in the Inlet, where we found dissipation rates five orders of magnitude higher than in the open ocean. These very high dissipation rates were caused by shear instabilities and wave breaking in large internal lee waves that formed on either side of the sill during both flood and ebb (Figs. 1 and 2). The very high dissipation rates were quite local to the sill, generally dropping off to levels an order of magnitude higher than the open ocean as close as 1 km away from the sill. Nonetheless, this mixing accounts for only 10% of the energy lost over the sill from the surface tide. The remainder of the energy must have radiated away from the sill as progressive internal tides, either as linear waves or as non-linear "solibores," to be dissipated elsewhere in the Inlet.

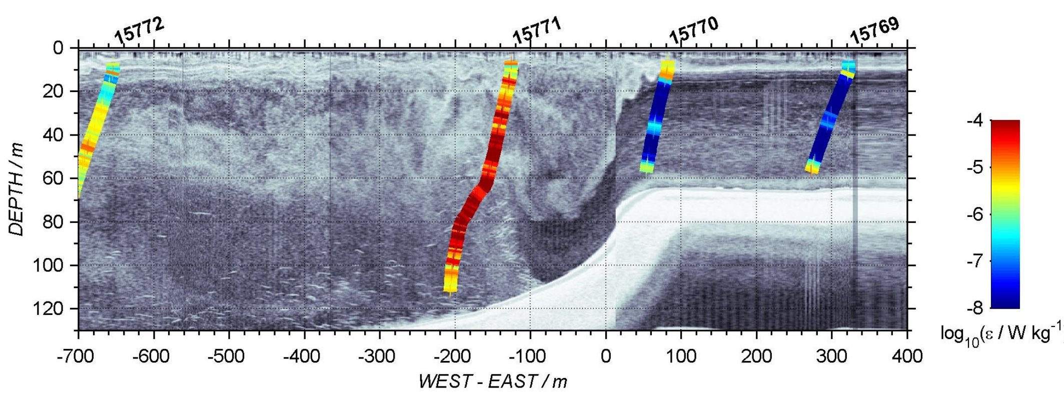

Fig. 1. The paths of four AMP drops over the Knight Inlet sill are colored by the strength of the turbulent dissipation, ε. The profiles were taken during ebb tide. Drops upstream of the sill crest (15770 and 15769) found low turbulence, about 10^{-8} W kg^{-1}. The Drop in the lee of the sill (15771) showed strong turbulence, about 10^{-4} W kg^{-1}, throughout most of the water column. Just 0.5 km downstream, ε decreased to about 10^{-6} W kg^{-1}, illustrating how the mixing is tightly confined to the sill.

We measured turbulence directly with the Advanced Microstructure Profiler (AMP) and indirectly by observing the length scales of turbulent overturns compared to the background stratification, N^2, with the SWIMS towed body. Because we could use up and down traces from SWIMS and it completed profiles more rapidly, it gave the more detailed view of the spatial structure of the mixing. The magnitudes determined indirectly from SWIMS were consistent with those measured directly with AMP.

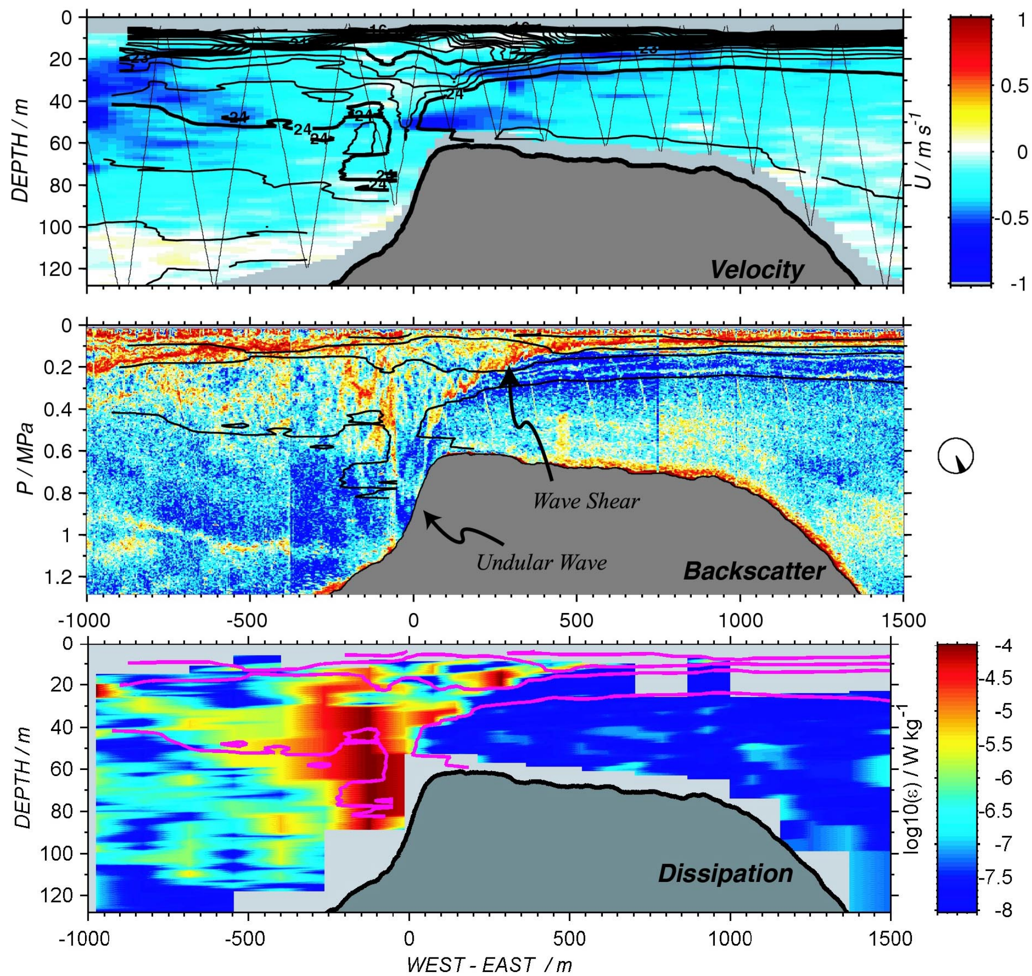

Fig. 2. The top panel shows velocity from an ebb tide similar to the one sampled in Fig. 1. The light saw tooth tracks are the paths of the SWIMS towed body. The middle panel shows the intensity of acoustic backscatter overlaid with isopycnals in black. The bottom panel shows □ obtained from the length scales of turbulent overturns observed with SWIMS, our depth-cycling towed body. Owing to the much tighter sampling, SWIMS gave a more detailed view of the mixing than did the AMP profiles. This figure shows the turbulence from a similar ebb tide, but with turbulence derived from density overturns measured by SWIMS.

The CMO96 measurements revealed average diapycnal diffusivities, K_ρ, similar in magnitude to those found in the open ocean, but occurring more episodically. Half of all thermocline mixing during the CMO experiment occurred during the passage of strongly nonlinear internal solitary waves, or solibores. These waves have been observed in a wide variety of locations around the world, and are usually created by interaction of a barotropic flow with sharp topography. Solibores appeared episodically at our site, with four strong events during our profiling periods, and were believed to be propagating shoreward from the shelfbreak. Velocity contours from a sample solibore packet are shown in Figure 3. Each pulse within the packet displays a strong first mode character, with onshore flow above the thermocline, offshore flow below, and isopycnal displacements up to 18 m (overlain in black). Within each wave of the packet, increased shear and strain pushed a portion of the water column close to or above the threshold for shear instability. The horizontal velocity was strongly sheared in each wave trough, and the Froude number was pushed close to or above the threshold for shear instability).

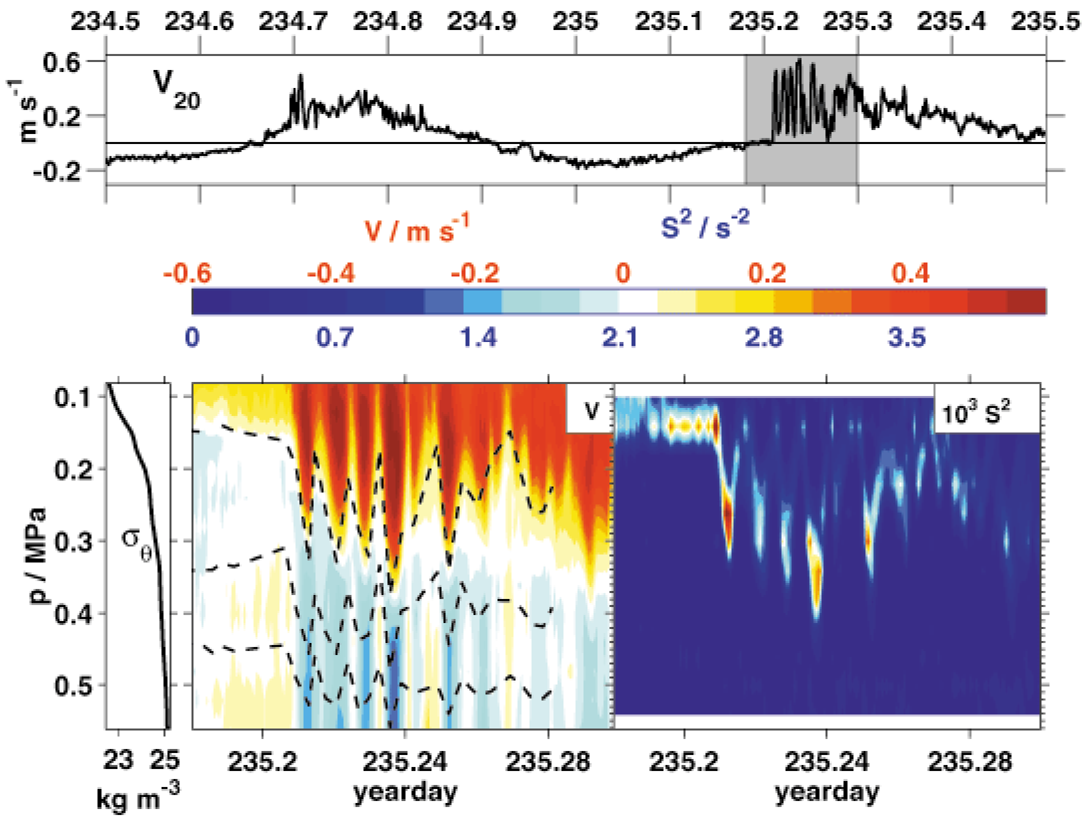

Fig. 3. Observation of a solibore on the continental shelf south of New England during CMO96. The time series of northward velocity, V, at 20 m shows two cycles of the twice-daily tide. Short pulses accompany both flood tides; both the background flow and the pulses are positive. The pulses are solibores. The lower two panels contain profiles versus time of velocity and shear variance during the second solibore.

Both dissipation and diffusivity were elevated over 100 times their pre-solibore. High dissipation in the trough of each solibore pulse occurred in water that had advected downward with that pulse, not water that normally occupied that depth range. Hence the net effect of high dissipation within the solibore was an enhancement of mixing in a relatively small range of isopycnals that usually occupied the thermocline. The effect of solibores on cruise averages is visible in Figure 4, which shows average diffusivity and buoyancy flux calculated with and without inclusion of the four strongest solibores (in both cases averaging was done along isopycnals and boundary layers were excluded). Though the strong solibore dissipation on yearday 235 (Figure 3) lasted only a few hours, it alone accounted for a third of all thermocline buoyancy fluxes. The intermittence of these strongly dissipative waves is a first order feature of the CMO96 shelf mixing, and is not well captured by use of average mixing profiles.

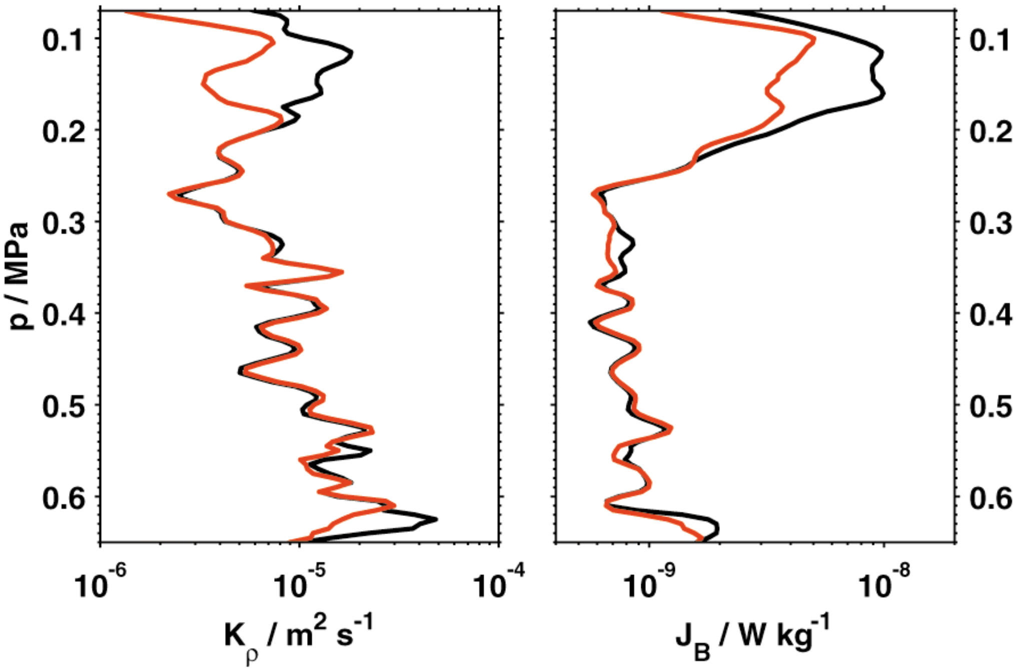

Fig. 4. CMO96 average diapycnal diffusivity and buoyancy flux with (black) and without (red) the four strongest solibores.

IMPACT/APPLICATIONS

Sills occur at the entrances of most estuaries and in most straits. The Knight Inlet observations are the most detailed made of mixing in sill flows and are being used to test numerical models of sill flows.

The CMO96 data are being used for the analysis of the Synthetic Aperture Sonar Primer that was conducted simultaneously at the same site. On a broader scale, the results are the first two-week-long time series of shear and mixing on a continental shelf and hence the first to illustrate the role of inertial and tidal forcing of mixing. They are expected to guide the development of numerical models to incorporate more realistic mixing parameterizations.

TRANSITIONS

None known.

RELATED PROJECTS

The Hawaii Ocean Mixing Experiment (HOME) is being conducted in September and October 2000 using equipment, techniques, and scientific results developed by this program. EPIC2001, a study of the warm pool in the eastern tropical Pacific, has just been funded by NSF as a part of CLIVAR. Our contribution will also have the same reliance on the earlier work under this program.

PUBLICATIONS

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